ENGINEERING CASE LIBRARY

ECL 120A

HARVEY LA BRANCHE

# Spring Failures in a New Toy Rifle (A)

All seemed well with the "Crrackfire Rifle", a new toy soon to be introduced to the stores by Mattell Inc. in mid-1966 as "engineering pilot testing" began. Firm orders for thousands of rifles had been taken from customers at the February toy show in New York and production tooling was well underway, much of it complete. Some hand-made samples of the gun had been assembled, then cocked and fired over 6,000 times without failure. "We all figured that with normal debugging it would be fairly easy to reach the target life of 5,000 shots", commented Harvey LaBranche, Director of Product Development Engineering. Then some phosphor bronze clutch springs began to break on the first batch of 100 guns which had been assembled from production parts. After several days of trying to cure the problem the weekend arrived. Mr. LaBranche took some data on the gun home with him resolved that he would "pull thoughts together" about what should be done next.



Prepared in the Design Division, Mechanical Engineering Department, Stanford University by Karl H. Vesper with support from the National Science Foundation. Cooperation of Mr. Harvey LaBranche, Mr. Jack Ryan and the Mattel Toy Company on making this material available is gratefully acknowledged.

Crrackfire Rifle Project

Mr. Jack Ryan, the company's chief of preliminary design, recalled how the Crrackfire project began. "We'd been very successful with toy guns, and we'd decided that we should come out with at least one new gun per year. This year we thought we'd make it a rifle. We thought kids might like a gun better if it were louder, so we tried some experiments to make toy guns as loud as possible. But we found that children were as much impressed with a sound that was long as they were by one that was loud, and that put us on the track of trying to make a gun with a long noise.

"The company makes some talking dolls and other toys that use a little phonograph mechanism we designed several years ago. The record can be made to play any noise you might want, so it seemed natural to try adapting it to a gun. Another company, Daisy, sold a gun that made a riccochet sound by spinning a ratchet weeel with fine teeth on it. We decided to try for a more realistic sound using a record."

In appearance the Crrackfire was modeled after the "Winchester 73" familiar to cowboy lore. To fit small boys the rifle was scaled down out of proportion to leave it with a realistic "feel" and also to allow room for the phonograph mechanism in the butt. Exhibit A-1 shows a picture of the gun. Royalty arrangements were made with the Winchester company for use of its name on the gun.

Mattel management expected the gun would be particularly attractive for summer play and that competitors who had already seen it at the toy show would soon introduce imitations. For several years Mattel had been introducing new toys at a high rate to stay ahead of competitive copies. Of the expected sales of $135/million in 1966, approximately $80/million were to be either new toys or major redesigns. Ideas for new toys were sought from many sources, including outside inventors and invention firms as well as engineers employed by Mattel, and the time pressure for completion of designs ready for market was intense. Usually from six months to two years were required to see a toy from the original idea through engineering, production and delivery to stores. Orders for delivery were normally first taken at the Toy Show in February. Production and delivery then might follow around March. Selling usually ended around November, before the last Christmas deliveries.

Notes of the Crrackfire project engineer, Mr. Robert Rosen, showed that he

began in August, 1965 by studying the problem of how to equip the gun with a phonograph which would be wound by the cocking lever and set in motion when the trigger was pulled to produce the "bang" followed by the "zinnnng" of a riccocheting bullet. Extensive engineering data had already been accumulated for the talking doll phonographs in studying the problems of how much winding power children should apply, life and wear properties, etc. Mr. Rosen chose a linear compression spring (whose maximum force in the fully cocked position of the rifle was 15 pounds) to propel the record mechanism and a centrifugal governor to regulate speed as the spring accelerated the record from rest and then grew weaker (down to 7 1/2 pounds) as it expanded to its limits within the gun housing. He computed the force required to cock this spring and compared it to information available in the company files about the strength of boys and also to other toy rifles such as the Daisy.

For the total life requirement of parts in the gun he estimated 6,000 shots by the procedure shown in his notes which are copied in Exhibit A-2. Mr. Ed Stasney, the man to whom Bob Rosen reported, and who himself reported to Harvey LaBranche estimated a requirement of 10,000 shots. Other reliability calculations Bob made included sizes for various bearings in the gear train and strengths of those parts he was unsure of and considered critical. Data later obtained by the Mattel Marketing Department on the cocking strengths of boys with the Crrackfire appear in Exhibit A-3.

Mechanism Operation

As depicted in Exhibit A-4, cocking the rifle slid a rack gear compressing the linear compression spring. At the limit of compression travel the trigger caught the end of the rack to hold it. Pulling the trigger then would release the rack, letting the linear spring push the rack forward to turn the gears of the record mechanism and spin the record. The tone arm carrying the record needle was carried, picked up and carried back to its starting position on the record by the rack during cocking. A stop which was cast into the gunstock prevented the needle from being carried too far.

The gear train between rack gear and record included a one-way clutch so that during cocking the moving rack would not spin the record backwards. Bob

had chosen a "spring clutch" for this purpose similar to those used in some of the talking dolls. As illustrated in Exhibit A-5, this spring was wound so it fitted with light pressure around the record clutch gear. It was free to turn around this gear in the direction which tended to unwind it but would bind tight around the gear hub if turned in the opposite direction.[1] One end of the clutch spring extended tangentially away from the gear hub and had its tip wrapped around a protrusion on the record disk. The clutch gear and spring around it fitted concentrically into a recess in the record hub. Then when the clutch gear was turned in one direction the record could remain still. But turning the gear in the other direction tended to rub the spring tighter on the gear hub, thereby wrapping it tight and pulling the record with it to produce the gunshot sound.

Bob based his design calculations for the spring clutch in part on two magazine articles.[2] He concluded from these calculations that he could make use of some flat spring wire already in stock at Mattel for talking doll mechanisms. This was considered an advantage, since lead time on delivery of different size wire was expected, based on recent experience with suppliers, to be approximately twelve weeks. A machine drawing of the spring appears in Exhibit A-6.

## Spring Failures

"I got pulled into this particular project more and more as the schedule got tighter", Harvey LaBranche recalled. "I dropped in on the model shop when the first few guns were put together by hand. They were tested and worked fine. Bob Rosen's calculations also looked good. He had done a stress analysis on

---

[1] To imagine how this spring clutch works, wrap a piece of paper around your finger tightly. Then holding the paper with your other hand notice how you can rotate the finger in the paper easily in one direction but not in the other. Your finger here is simulating the clutch gear hub and the paper is simulating the spring, one end of which is fastened to the record.

[2] Radnickas and Fine, Machine Design, May 13, 1965, page 182. Kaplan, Product Engineering, August 31, 1959, page 30.

the clutch spring which said it had a safety factor somewhere between five and seven. One of those first guns was tested through 13,000 shots without any problems. The other two of the first three all went over 6,000. So it looked like things were fine."

Then a batch of 100 guns was assembled for what was referred to as the "Engineering Pilot Test". Harvey helped with assembly and then with testing as Bob Rosen and some girls from the production line began to cock and trigger the guns, keeping track of the number of shots with pencil marks every five shots. As the count wore on various failures began to occur; stripped gears, jammed rack, no sound when fired. But the only repeated difficulty was failure of the clutch. Disassembly of the guns showed that the clutch spring snapped in two just where it straightened out to reach a fastening on the record (depicted in Exhibit A-5).

The failures were discussed and Bob suggested some possible causes and remedies. The first theory he advanced was that the clutch springs had been improperly heat treated by the company which supplied them. He called the supplier and asked for a batch of springs whose manufacture was extra carefully controlled for quality, letting it be known that Mattel would carefully check the batch in its own laboratory to assure that specifications had been met. These springs arrived, were tested in the lab, tried in rifles, but produced the same rate of failure. Some steel springs (stiffer material, its modulus of elasticity, E, being 30,000 $lbs/in^2$ as opposed to an E of 15,000 for the first phosphor bronze springs) were also tried, but failed even sooner than had the bronze springs.[1]

Bob also suggested that breakage might be due to a stress concentration where the last coil straightened out to fasten to the record. In operating the gun this coil tended to be bent across the one adjacent to it (see sketch in Exhibit A-5), thereby imposing an additional stress. By careful assembly some guns were put together in such a way as to prevent this bending; the failures still continued.

---

[1] Allowable maximum stress for phosphor bronze was estimated at 60,000 psi, and that for steel at 150,000 psi to avoid early onset of failure.

Harvey raised the possibility that some clutches might slip somewhat before grabbing, allowing the drive gear powered by the linear compression spring to pick up momentum which tehn slammed into the clutch spring and accelerated the record when the clutch finally grabbed. He devised a method for measuring slip torque (his notes are copied in Exhibit A-7 illustrating the method) and concluded that all clutches could be expected to take hold after the same rotation of about 30°. He noted that there was also some play in the gear train which he estimated would allow the rack an additional 0.010 inches of free travel (see Exhibit A-4 for dimensions and other data on the gears). Thus, he saw two sources of play which could allow buildup of energy to be slammed into the various elements of the drive train when it finally took hold.

Part of this energy then would be absorbed by the straight segment of clutch spring between the last coil around the clutch gear hub and the fastening on the record disk. This energy would stretch the straight section inducing a stress in it which might cause the failure. The amount of this stress could be deduced by the technique of strain energy analysis.[1] He believed the relation for computing stress in the straight section of clutch spring could be computed as follows:

$$\text{Stress in Spring} = \frac{2 \times (\text{energy}) \times (\text{elasticity modulus, } E)}{(\text{spring cross section area}) \times (\text{straight length})}$$

Harvey described what made him think of this analytical method. "The puzzling question is why bronze, the weaker material, should not fail sooner than the steel. About fifteen years ago when I worked for a company manufacturing fork-lift trucks I remember an engineer making a part stiffer by heat treating it, and finding it failed sooner. He used the strain energy approach to calculate stress and figured out that the part needed to be more elastic. I also remember hearing about an aircraft engineer at Boeing who

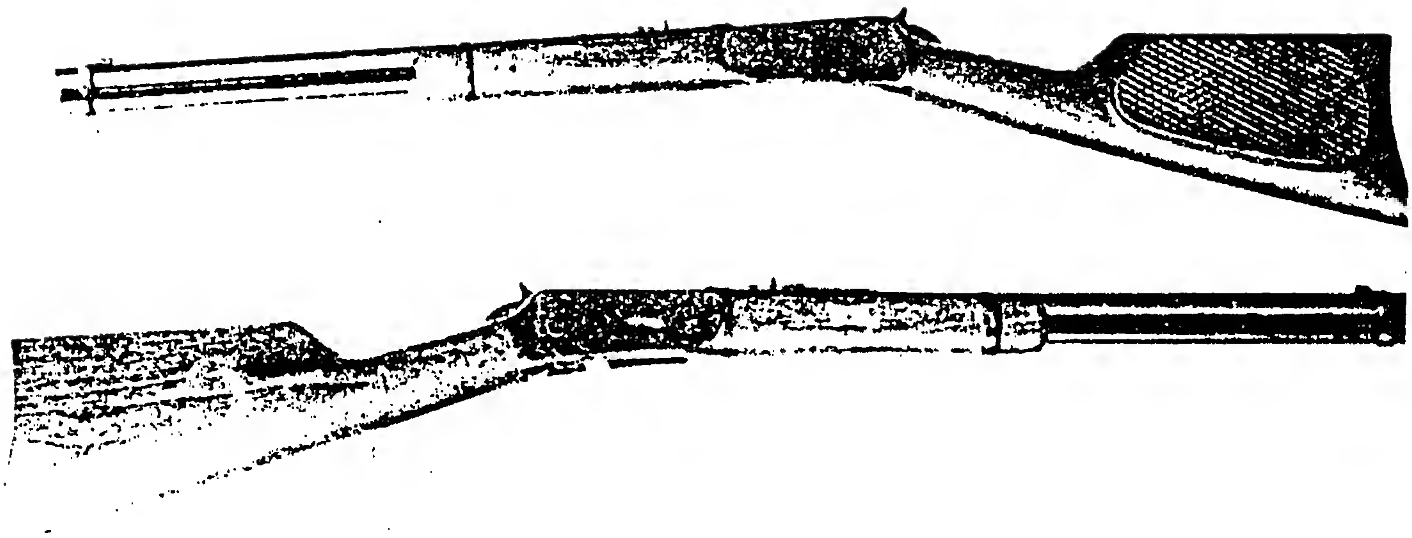
[1] For references on strain energy, see a strength of materials text.

had a similar experience."[1]

[1] Harvey's experience after graduating with a B.S.M.E. from the University of Washington in 1949 had included 5 years with the fork-lift truck company, two years with a University Research Laboratory and seven years with a hardware manufacturer before joining Mattel. He had also taken evening coursework in art and drawing after graduating from college. "I liked to draw and used to think I'd become an artist", he recalled, "but math was easy for me and engineering seemed more practical."

Exhibit A-1 Crrackfire Rifle





Ex. V

R. Rosen

LIFE EXPECTANCY OF GUN & RECORD

ASSUME FOLLOWING:

1. EACH SHOT WILL TAKE 2 MIN TIME
ACTUAL TIME 2 SEC. (ALLOWANCE FOR REST)

2. ON DAYS THAT GUN IS PLAYED
WITH THE TIME WILL BE 2 HOURS

3. THE NO. OF DAYS IN YEAR
WILL BE 1 OUT OF 4 OR $\frac{365}{4} = 88.7$

4 MINIMUM LIFE 1 YEAR

THERE FORE

TOTAL MINIMUM NO OF SHOTS $= \frac{120}{2} \times 88.7 = 5,320$ SHOTS

SAY 6000 SHOTS

10,000 PER Ed Spastney

TO: Bob Dougherty

FROM: Marketing Research - Ralph Westfall

DATE: May 10, 1967

SUBJECT: Crrackfire Rifle Cocking Torsion Study

OBJECTIVE: To determine the extent to which boys of different ages have obvious difficulties in cocking Crrackfire rifles with varying amounts of torsion in the cocking mechanism.

METHOD: A total of 48 boys between the ages of 7 and 12 were observed while cocking and firing Crrackfire samples with cocking torsions between 11 and 37 lbs. Children were recorded as having difficulty if they failed to cock the rifle on the first attempt.

FINDINGS: Reactions to the Crrackfires used in this test indicate that the maximum torsion specified for current production (15 lbs.) is an appropriate upper limit for cocking this gun. The only satisfactory modification would be a reduction, not an increase, in this 15 pound limit.

The findings are summarized in the following chart:

Percent of boys who succeeded in cocking on first attempt

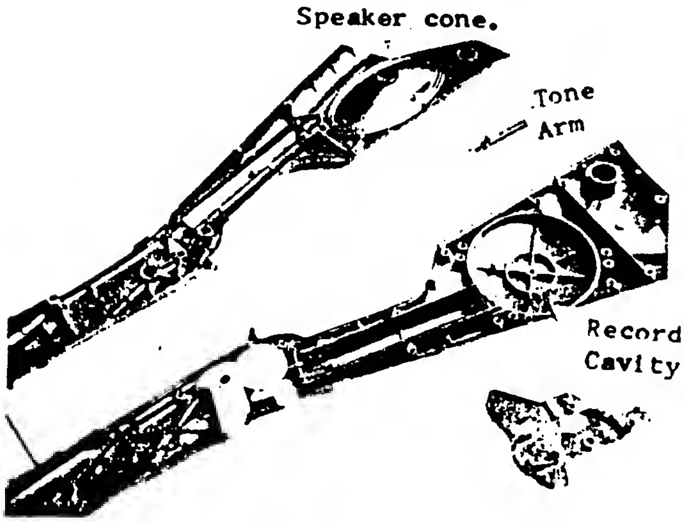
| Torsion in Pounds | Age: 6 - 8 yrs. | 9 - 11 yrs. |
|---|---|---|
| 11 - 18 lbs | 25% | 79% |
| 20 - 27 lbs | 19 | 52 |
| 30 - 37 lbs | 4 | 17 |

These data suggest that torsions of 18 lbs or below are probably satisfactory because the resulting "pull" makes cocking difficult for only the "little kids" who would ordinarily be expected to have to put extra effort into the mechanism. Torsions between 20 and 27 lbs seem to be satisfactory only for older boys. The data show that only 11 year old boys have no difficulty with this amount of pull; this is near the top of the age range for the toy. Torsions of 30 lbs or more appear to be completely unsatisfactory.

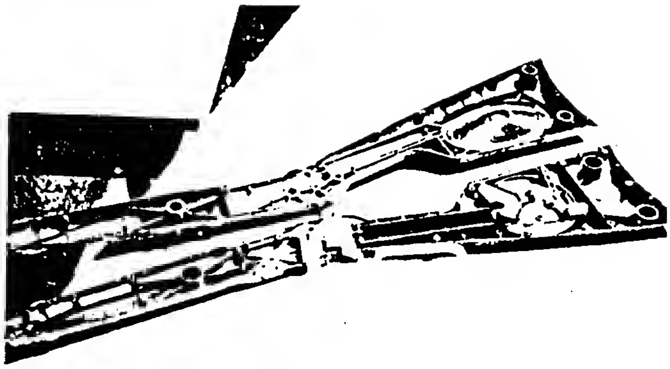
NOTE: A detailed cross-tabulation of the data by age is availabe on request from Marketing Research.

copies: Elliot Handler
Art Spear
Seymour Adler (2)
Jack Ryan (2)
Walt Ross (3)
Harvey LaBranche (2)
Jack Barcus (2)

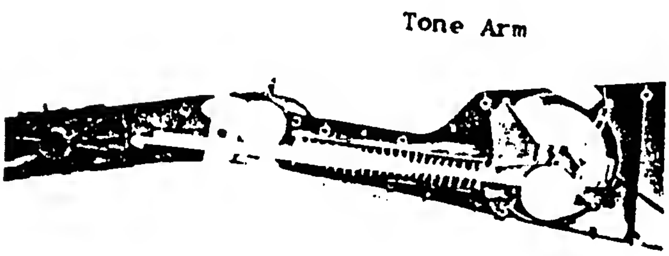
Exhibit 4 - Sound Mechanism Operation



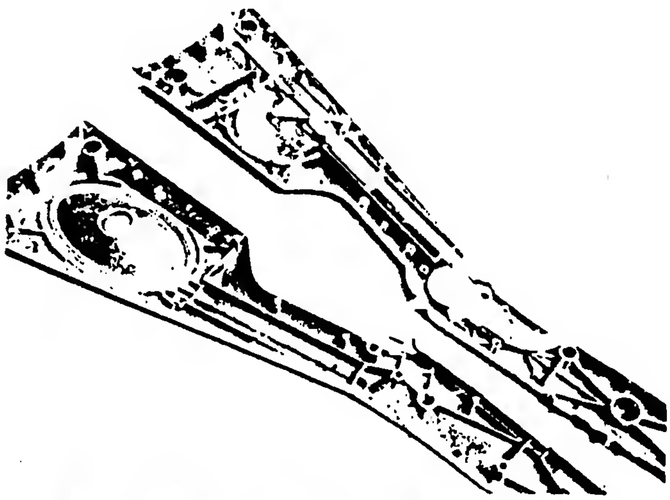

Two halves of gun housing. Speaker cone rubs directly on phonograph needle tone arm to pickup sound.



Record is in cavity with needle in place. Flyweights on outer edge of record fly out, rubbing against cavity to hold record speed down. Clutch gear in center of record has 12 teeth.

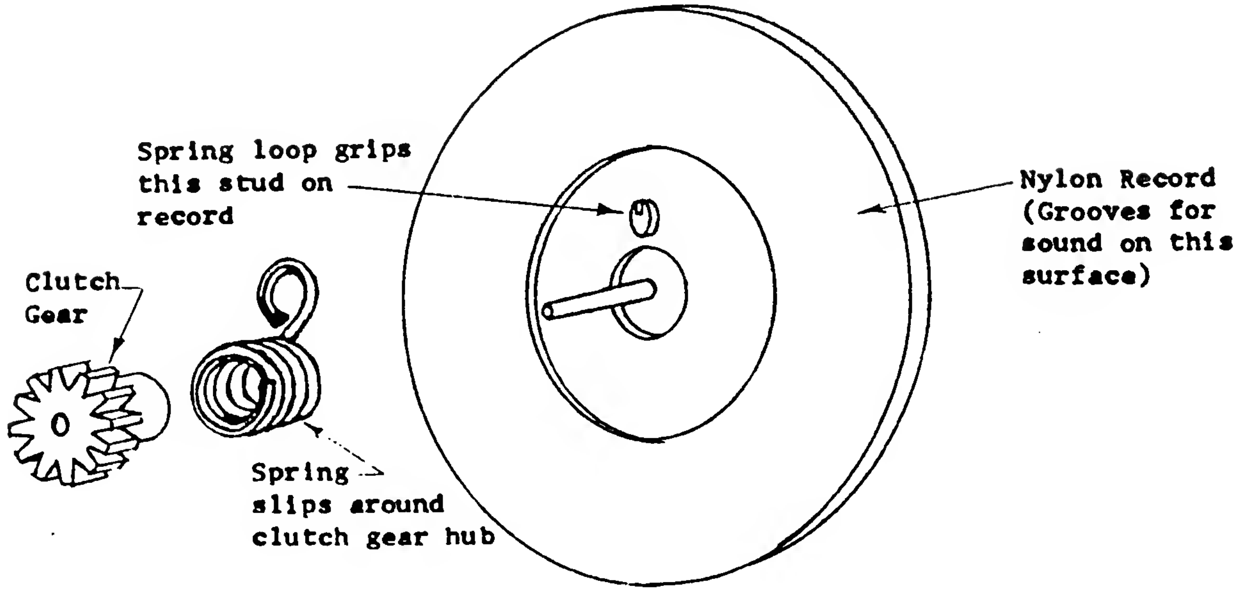



Rack with spring on it is in uncocked (fired) position. Tone arm has reached limit of travel and been picked up by end of rack. Rack drives gear with 10 teeth visible on top side (pitch radius of gear is 0.188") and 40 teeth not visible on bottom side meshing with clutch gear.

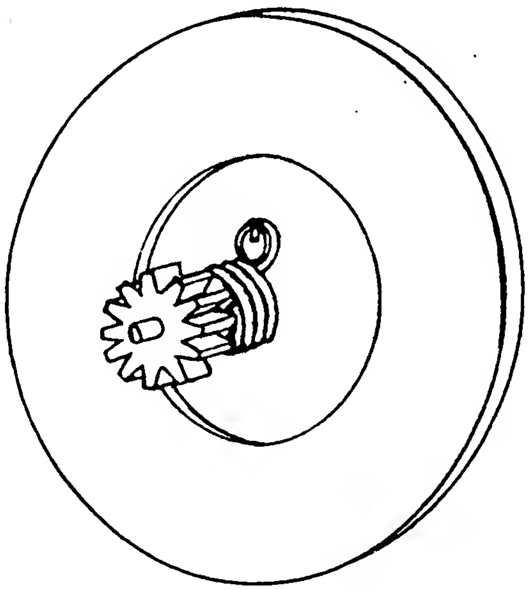


Mechanism with spring removed is now in cocked position. Rack has picked up tone arm, carrying needle to start of record. Trigger catches end of rack, holding rack back against what would be force of linear compression spring if it were installed.

Exhibit 5 - Schematic Drawing of Clutch Mechanism 




Assembled Mechanism



Clutch Spring

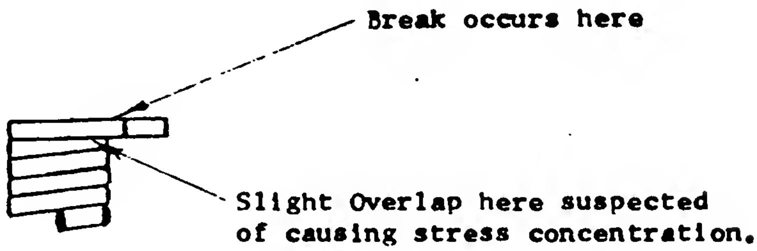
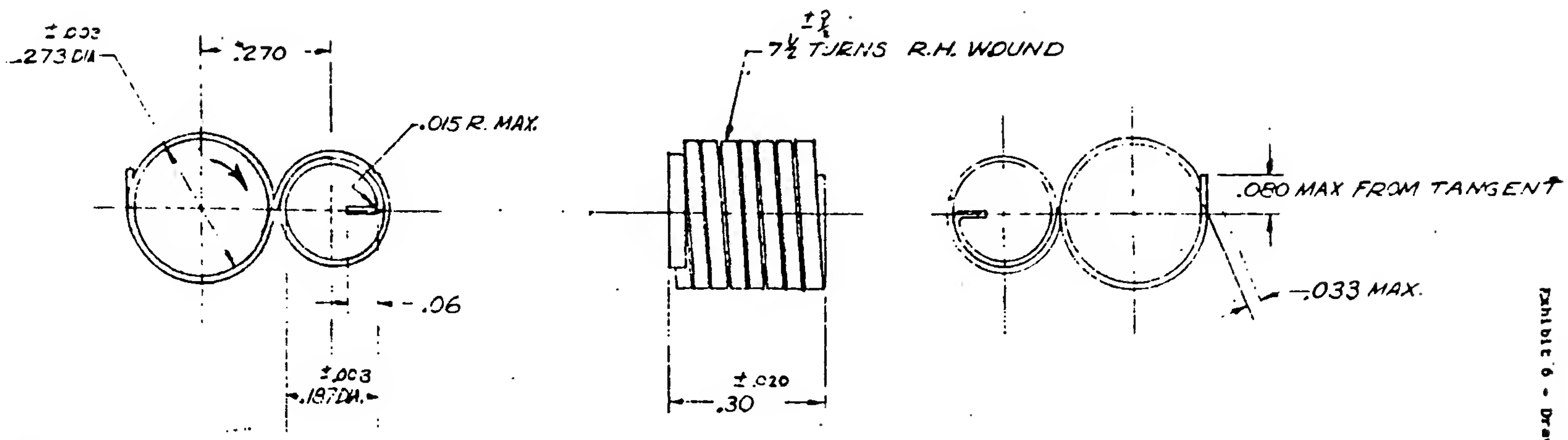
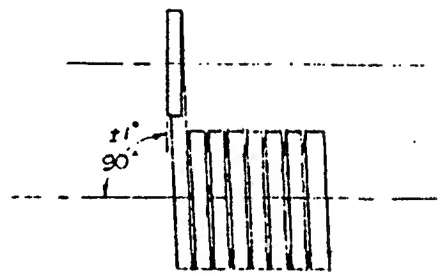


Exhibit 6 - Drawing of Clutch Spring




PERFORMANCE SPECIFICATIONS

1. MOUNT SPRING ON .280 DIA. ARBOR & .187 DIA. ARBOR SPACED .270 IN APART EQUIV. TO ARBORS ON 5520-002 RECORD & 5520-034 CLUTCH SHAFT.
2. WHEN .280 DIA ARBOR ROTATED AXIALLY IN DIRECTION OF ARROW, SPRING TO "LOCK ON" TO ARBOR AND NOT SLIP @ 11 IN. OZ. TORQUE MIN.
3. WHEN .280 ARBOR ROTATED OPPOSITE TO DIRECTION OF ARROW, SPRING TO SLIP AT LESS THAN 11 IN OZ. TORQUE

NOTES:

1. PHOSPHOR BRONZE FLAT WIRE .036 ±.002 X .012 ±.0015 ASTM B 159 ALLOY A

| DET | DESC. | REQ. | MAT'L | NO REQ. |
|---|---|---|---|---|
| TITLE: CLUTCH SPRING | DRAWN BY: R.R. | DATE: 12-2-66 | PROJ ENG: R. R. | DATE: 12-2-66 |
| | DESIGNED BY | | SPECIALIST | |
| | CHECKED BY | 11-4-66 | [illegible] | 11-4-66 |
| | SWood | 11-4-66 | | |
| TOLERANCE: DECIMAL .XX ±.01, .XXX ±.005 · FRAC ±1/64 · ANG ±1/4° | MATTEL INC. 8150 ROSECRANS AVE., HAWTHORNE, CALIF. | | | |
| MAT'L: SEE NOTE NO 1 | DWG. NO. 5520-028 | | | |
| SHEET NO. | SCALE | | | |

Exhibit 7 - Mr. LaBranche's Notes

9-66

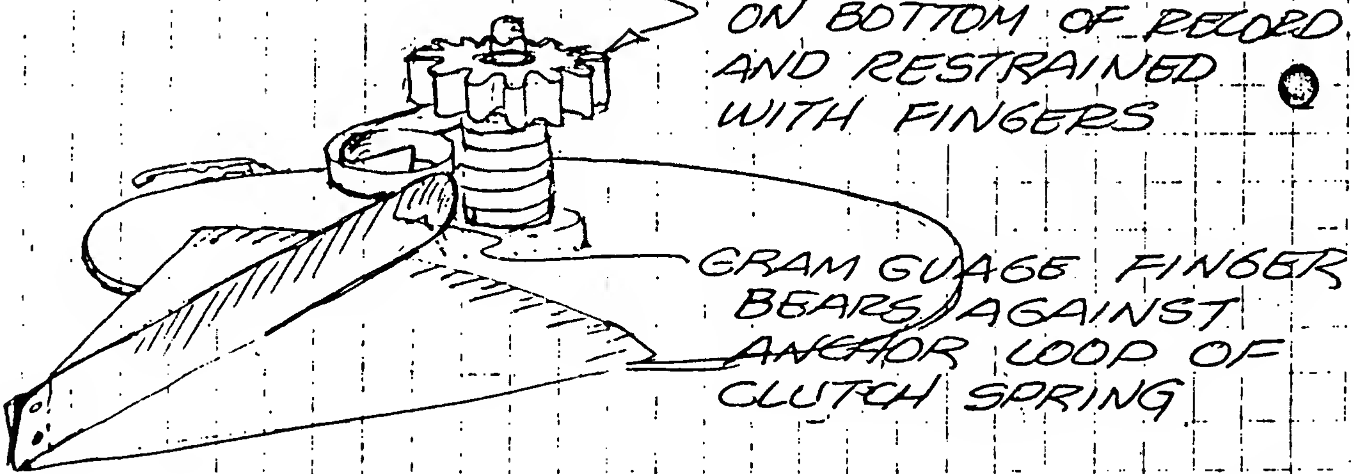
H. LABRANCHE

5520 ENGR. PILOT TEST RESULTS (4-7-66)

24 GUNS WERE ASSEMBLED, USING STEEL CLUTCHES.

GUNS WERE HAND TESTED ON SWING SHIFT, TO DETERMINE FAILURE RATE, AND CORRELLATION, IF ANY, WITH CLUTCH SLIP TORQUE IN THE SLIP DIRECTION.

SLIP TORQUE WAS MEASURED AS SHOWN IN THE SKETCH BELOW.




TEST RESULTS, AND OTHER OBSERVATIONS, ARE NOTED HEREIN.

Exhibit 7 - Mr. LaBranche's Notes (Continued)



| NO. | GRAMS @ SLIP | CYLES TO FAILURE | CAUSE |
|---|---|---|---|
| 75 | 22 | 2920 | CLUTCH |
| 76 | 25 | 3220 + (OK) | |
| 77 | 28 | 2400 + (OK) | |
| 78 | DID NOT USE THIS NO. | | |
| 79 | 30 | 10 | CLUTCH |
| 80 | 32 | — | NOT TESTED - EXCESSIVE DRAG |
| 81 | 35 | 2265 | CLUTCH |
| 82 | 35 | 1890 + (OK) | |
| 83 | 38 | 950 + (OK) | |
| 84 | 38 | 280 + (OK) | |
| 85 | 40 | — | NOT TESTED (NO SOUND) |
| 86 | 44 | 4360 + (OK) | |
| 87 | 40 | 1400 + (~~OK~~) | JAMMED RACK (PROB. CLUTCH) |
| 88 | 42 | 4615 + (OK) | |
| 89 | 42 | 810 + | |
| 90 | 42 | 3970 − | CLUTCH |
| 91 | 44 | 4560 + (OK) | |
| 92 | 46 | 3370 + | GEAR DISENGAGE |
| 93 | 48 | 2100 + (OK) | |
| 94 | 48 | 1100 | GEARS STRIPPED |
| 95 | 48 | — | NOT TESTED |
| 96 | 48 | 3600 + (OK) | |
| 97 | 48 | 3280 + (OK) | |
| 98 | 48 | 3160 + (OK) | |
| 99 | 53 | 2870 + (OK) | |
| 100 | 67 | 2820 | CLUTCH |

6 CLUTCH FAILURES OUT OF 22. (27.3%)

NO APPARENT RELATIONSHIP TO SLIP TORQUE.

SO ALL CLUTCHES MAY BE ASSUMED TO "GRAB" AFTER THE SAME RACK TRAVEL

# ENGINEERING CASE LIBRARY

ECL 120B

HARVEY LA BRANCHE

Spring Failures in a New Toy Rifle (B)

Having decided to use the strain energy method to determine the stress induced in the clutch spring of the Crrackfire Rifle Mr. LaBranche proceeded with the analysis shown in his notes, which are copied in Exhibit B-1. His conclusion was that the overlap of the end coil and the strain energy stress accounted for the failures. Next he thought he should check his calculations and the assumptions on which they were based. Then he expected to go on to consideration of alternative remedies. A heavier spring might, he thought, withstand the stress better, but it would also be less flexible, which meant it would have to be fitted more closely and more accurately to the clutch gear hub in order to grab and release as it was intended to. The tighter tolerances would, in turn, raise costs in manufacture.

He was convinced that any changes to be made would have to be fitted into the existing "envelope" of the record mechanism. A sketch showing the dimensions of this envelope appears in Exhibit B-2. The gunstock housing left very little extra space, and to retool it to different dimensions might take from four to six months. Furthermore, approximately $30,000 worth of stocks were already on hand which would then have to be scrapped. Tooling for a smaller item, such as a different record or clutch mechanism configuration, might take less time, possibly three weeks, but even this delay he considered undesirable, since each day of delay would represent a sales loss of several thousand dollars. "Anything that isn't simple and quick is bound to be terribly expensive", he observed.



Prepared in the Design Division, Mechanical Engineering Department, Stanford University by Karl H. Vesper with support from the National Science Foundation. Cooperation of Mr. Harvey LaBranche, Mr. Jack Ryan and the Mattel Toy Company on making this material available is gratefully acknowledged.

CLUTCH BREAKAGE ON 5520

Date: 4-9-66

H. LaBranche

5520's ASSEMBLED DURING THE ENGINEERING PILOT HAVE DISPLAYED AN INTOLERABLY HIGH LEVEL OF CLUTCH FAILURES.

THIS WEEK, APPROXIMATELY 25 GUNS WERE ASSEMBLED WITH STEEL CLUTCHES, AND 25 WITH PHOSPHOR BRONZE.

BREAKAGE RATE ON STEEL CLUTCHES WAS 27% (GUNS TESTED TO 3000/5000 CYCLES).

BREAKAGE RATE ON PHOSPHOR BRONZE CLUTCHES WAS 12%, ALTHOUGH PHOSPHOR BRONZE HAS A LOWER FATIGUE STRESS THAN STEEL.

DESIGN STRESS IS ABOUT 12,000 PSI ON THE BRONZE CLUTCHES, AND ON STEEL, ALSO ABOUT 12,000 PSI. BOTH ARE WELL BELOW FIGURES RECOMMENDED BY VARIOUS DESIGN SOURCES.

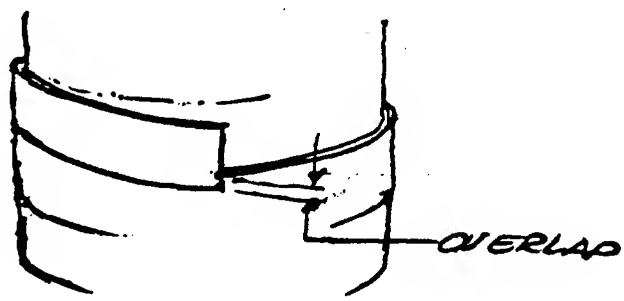
SINCE ALL GUNS WERE ASSEMBLED OUT OF THE SAME LOT OF MATERIALS, AND BY THE SAME ENGINEERS, SOME FACTORS NOT PREVIOUSLY CONSIDERED MAY BE ASSUMED TO BE INVOLVED:

IT WAS MY THOUGHT THAT THE FAILURES MIGHT BE CAUSED BY CLUTCHES THAT SLIPPED OCCASIONALLY, AND LOCKED UP ONLY AFTER THE RACK HAD ACELLERATED FORWARD FOR SOME DISTANCE (CAUSING EXCESSIVE MOMENTARY LOADS).

IT WAS FURTHER THOUGHT THAT IF THIS WERE THE CASE, THERE SHOULD BE SOME CORRELATION BETWEEN REVERSE SLIP TORQUE, AND PREMATURE FAILURE.

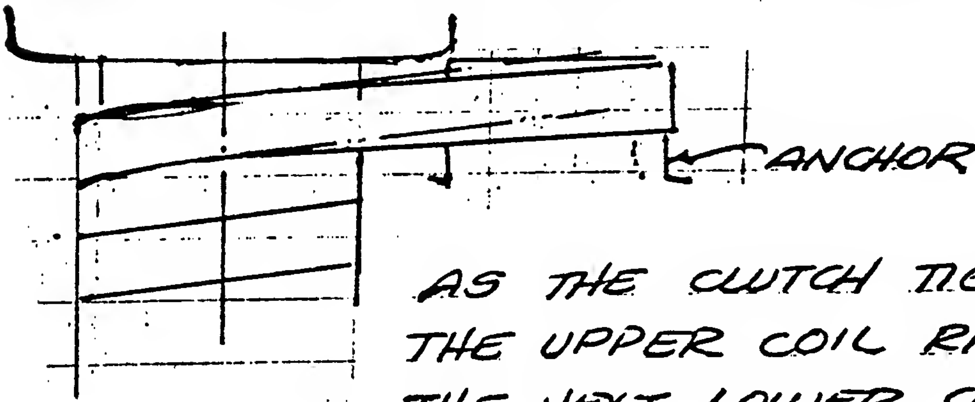
ALL GUNS ASSEMBLED THIS WEEK HAD CLUTCHES CHECKED FOR SLIP. BUT THE FAILURES DID NOT CORRELATE AT ALL.

~~FE~~ ALL OF THE GUNS FROM THE STEEL CLUTCH LOT HAVE BEEN EXAMINED. BROKEN CLUTCHES ALL FAILED AT THE POINT WHERE THEY LEAVE THE PINION SHAFT, AND MOST OF THE BROKEN ENDS OVERLAP THE NEXT LOWER COIL (SEE SKETCH)



GUNS WITH PHOSPHOR BRONZE CLUTCHES WILL BE EXAMINED MONDAY.

THIS OVERLAP IS APPARENTLY CAUSED BY AN INCORRECT LEAD-OFF ANGLE.




AS THE CLUTCH TIGHTENS, THE UPPER COIL RIDES OVER THE NEXT LOWER COIL.

THE RESULT IS THAT THE LOWER FIBERS OF THE LEAD-OFF COIL ARE OVERSTRESSED AT THE POINT OF CONTACT WITH THE CLUTCH SHAFT.

NO QUICK CURES FOR THIS CONDITION ARE APPARENT.

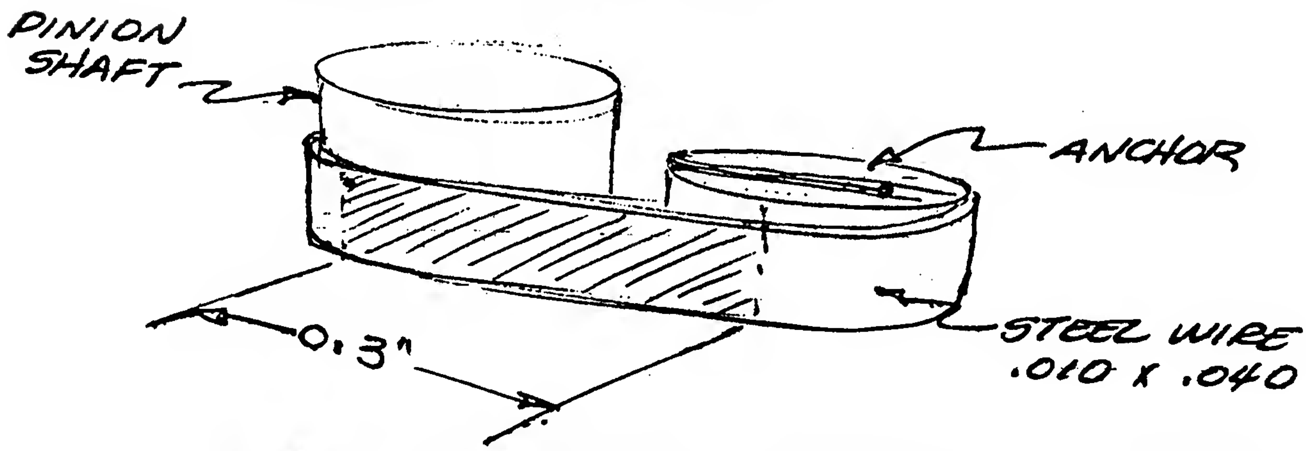
BUT THE PARADOX THAT STEEL CLUTCHES BREAK MORE FREQUENTY THAN PHOSPHOR BRONZE REMAINS.

WORKMANSHIP ON BOTH APPEARED EQUAL; SLIP TORQUES WERE IN THE SAME RANGE:

ONE EXPLANATION COULD BE STRESSES INDUCED BY ENERGY LOADING.

THE BRONZE, HAVING A LOWER MODULUS OF ELASTICITY, WILL ELONGATE MORE FOR A PARTICULAR STRESS LEVEL, AND THEREFORE WILL ABSORB MORE ENERGY.

CHECK FURTHER.




CONSIDER ENERGY STORED IN SHADED SECTION OF COIL.

LET LENGTH OF SECTION $= \ell$ in
CROSS-SECT. AREA $= A$ in$^2$
MOD. OF EL. $= E$ psi
ENERGY STORED $= W$ in-lb
$STRESS_{MAX}$ $= S$ psi
FORCE ON WIRE UNDER $S_{MAX}$ $= F$ lb

EXHIBIT B-1

UNIT ELONGATION OF WIRE = $\frac{S}{E}$

TOTAL " " " = $\frac{Sl}{E}$

FORCE AT START = 0 LB

FORCE AT END = F

SO AVERAGE FORCE = $\frac{F}{2}$

WORK DONE = (FORCE)(DISTANCE)

$$= \left(\frac{Sl}{E}\right)\left(\frac{F}{2}\right) = \frac{FSl}{2E}$$

FORCE F ALSO EQUALS STRESS X AREA, OR $(S_{\cancel{MAX}})(A)$

SO WORK DONE = $\frac{S^2Al}{2E}$

FACTORING, $S^2 = \frac{2EW}{Al}$

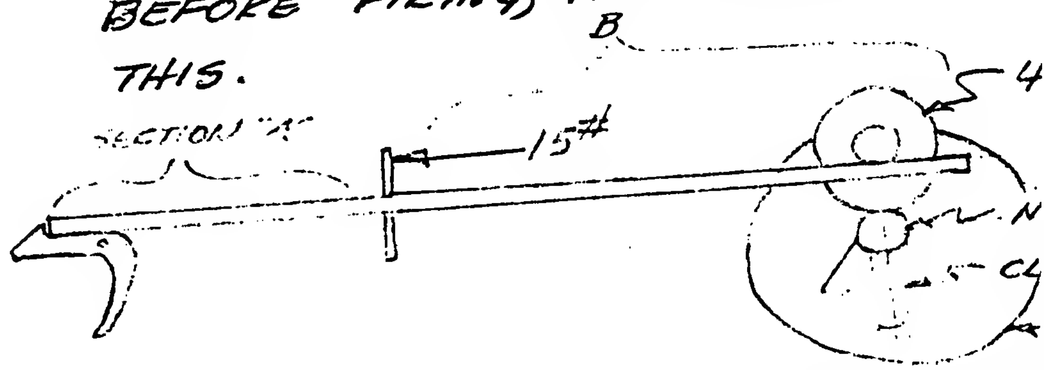
AND $S = 1.414\sqrt{\frac{WE}{Al}}$

LET US TRY TO APPROXIMATE THE AMOUNT OF WORK THAT MIGHT BE STORED IN THIS SECTION OF THE CLUTCH JUST AFTER FIRING THE TRIGGER.

EXHIBIT B-1

BEFORE FIRING, THE SYSTEM LOO

THIS.




AFTER FIRING, THE RACK IS ACCEL

FORWARD.

~~RELEASE OF~~
THE INITIAL COMPRESSION OF THE F
PART OF THE RACK (LABELED SECT
PLUS THE ELONGATION OF THE RE
OF THE RACK AS IT IS PUT UNDER

ASSUME A PERFECT MECHANISM,
THE RECORD IS LOCKED UP.

THE SECTION OF THE RACK LABELED
BE PUT UNDER TENSION, AND WILL
THE WORK TO ELONGATE IT WILL
THE ENERGY RELEASED BY THE S
SO IGNORE THIS WORK AS REGARDS.
THE CLUTCH.

NOW ASSUME .010" FREE PLAY BET
TEETH AND CLUSTER GEAR PINION.

EXHIBIT B-1

ECL 120B

NOW MEASURE ANGULAR MOVEMENT OF RECORD BETWEEN "FREE" AND "LOCKED CLUTCH" CONDITION.

MOVEMENT MEASURES 30°.

CLUTCH PINION PITCH RADIUS IS 0.188".

EQUIVALENT RACK TRAVEL WOULD BE

$$(0.188'')(2\pi)\left(\frac{30^\circ}{360^\circ}\right)\underbrace{\left(\frac{1}{4}\right)}_{\text{CLUSTER GEAR RATIO}} = 0.025''$$

TOTAL RACK TRAVEL, PRIOR TO RECORD MOTION, IS THEN 0.025" + 0.010" OR 0.035"

WORK DONE BY 15# SPRING IS

(15#)(0.035") OR 0.52 in. lb.

ASSUMING A LOCKED RECORD STILL, THE PARTS ALL COME TO A HALT, AND THIS WORK IS CONVERTED TO STRAIN ENERGY.

THE CLUSTER GEAR, THE PINION, THE CLUTCH, AND THE RECORD, WILL ALL BE STRAINED.

AN ANALYSIS OF THE AMOUNTS STORED IN EACH ELEMENT COULD BE MADE. BUT TO SEE IF THE APPROACH HAS ANY VALIDITY, ASSUME THAT ONLY 5% OF IT IS STORED IN THE 0.3" LONG.

CLUTCH TAIL.

SUBSTITUTE THIS IN THE STRESS FORMULA ON PG. 5 —

$$S = 1.414\sqrt{\frac{WE}{A\ell}}$$

$W$ = 5% OF 0.5 IN LB, OR 0.025 in lb

$E$ = 30,000,000 (STEEL)

OR 15,000,000 psi (PHOSPHOR BRONZE)

$A = (0.01")(0.04") = 0.0004"$ (STEEL)

OR $(0.012)(0.036) = 0.00043"$ (PH. BR.)

$\ell = 0.3"$

$-2+7+4+9$

$$S = 1.414\sqrt{\frac{(0.025)(30{,}000{,}000)}{(0.0004)(0.3)}}$$

$$= 1.414\sqrt{6250000000}$$

$$= (1.414)(79000) = \underline{112{,}000 \text{ psi}} \text{ (STEEL)}$$

$$S_{BRONZE} = 1.414\sqrt{\frac{(0.025)(15{,}000{,}000)}{(0.00043)(0.3)}}$$

$$= 1.414\sqrt{2910000000}$$

$$= (1.414)(54{,}000) = 76{,}000 \text{ psi (PH. BR.)}$$

NOW THESE RESULTS MAY BE WRONG BY A WIDE MARGIN, SINCE THEY ARE BASED ON AN ESTIMATE OF "OLD" BACKLASH, AND AN [illegible]

STORED IN THE CLUTCH LEG.

BUT IF WE ASSUME THAT NO BACKLASH EXISTS AT THE RACK/CLUSTER GEAR CONTACT POINT, THE ENERGY STRESSES WOULD STILL BE $\frac{25}{35}$ OF THE VALUES PREVIOUSLY CALCULATED.

NOTE ALSO THAT THE STEEL CLUTCHES ARE STRESSED 47% HIGHER THAN THE PHOSPHOR BRONZE CLUTCHES.

CONCLUSIONS

1. ORIGINAL DESIGN STRESSES DO NOT TAKE ENERGY INTO CONSIDERATION, AND ARE FAR LOWER THAN LIKELY ENERGY STRESSES.

2. OVERLAP OF LEAD-OFF COIL IS THE REASON BREAKAGE USUALLY OCCURS AT THE CLUTCH SHAFT END.

3. THE ONLY EXPLANATION FOR THE HIGHER FAILURE RATE OF THE STEEL CLUTCHES THAT APPEARS LOGICAL IS ONE BASED ON ENERGY ABSORPTION.

Exhibit B-2 - **Available Space In Record Cavity**

**Drawing shows cross-section of record cavity (unshaded area, twice actual size) which measures 3.2 inches in diameter by 0.360 inches deep. Position of gear teeth must stay the same to mesh with rack gear. Other dimensions of cavity are fixed by the configuration of the plastic housing which forms one side of the gun.**